X-693-70-252
PREPRINT

NASA TM X- 63966

ENERGETIC ELECTRONS ASSOCIATED WITH SOLAR FLARES AND THEIR RELATION TO TYPE I NOISE ACTIVITY

KUNITOMO SAKURAI

JULY 1970

GSFC

GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND

ENERGETIC ELECTRONS ASSOCIATED WITH SOLAR FLARES AND THEIR RELATION TO TYPE I NOISE ACTIVITY

by

Kunitomo Sakurai*
Radio Astronomy Branch
Laboratory for Extraterrestrial Physics
NASA, Goddard Space Flight Center
Greenbelt, Maryland

ABSTRACT

The generation of energetic electrons is always associated with the solar flares which occur within the sunspot groups that are highly active in emitting type I noise storms. The number of the solar flares which are associated with the distinct electron events observed at the earth tends to increase in association with the westward movement of these active groups. This tendency is not contradictory to the close association between electron producing solar flares and type I active regions if we take into account the limited directivity of type I noise storms associated with these sunspot groups.

The acceleration of the energetic electrons associated with solar flares seems to be closely related to the type I active regions where the enormous numbers of suprathermal electrons exist and play a role in generating these radio noise storms.

* NAS-NRC Associate with NASA

INTRODUCTION

Energetic electrons of kinetic energy $\gtrsim$ 40 Kev are usually generated by solar flares of importance equal to or greater than 1- (Van Allen and Krimigis, 1965; Anderson and Lin, 1967). Recently, these energetic electron events were classified into two distinct types; Simple and Complex (Lin and Anderson, 1967; Lin, 1970). The latter are always associated with solar flares which take place within the active regions where type I noise storm activity is high. This result suggests that, in such active regions, many solar flares which can produce energetic electrons occur and furthermore these electrons can propagate along the lines of the interplanetary magnetic field passing through the earth's neighborhood after the ejection from active regions.

By using the earlier observational data, Sakurai (1967) has shown that most solar flares which produced the energetic electrons were associated with the impulsive microwave radio bursts. This author also discussed the acceleration mechanism of these electrons by taking into account possible energy loss processes in the flare regions. The energy range of accelerated electrons has been estimated to be of the order of magnitude from 10 to 100 Kev.

Lin (1970) shows that these electron events are also usually associated with the X-ray bursts which are emitted from the same flares. Then, the electron acceleration processes seem to be well correlated with the emission mechanism of microwave impulsive and X-ray bursts. As Lin and Anderson (1967) and Lin (1970) have shown, the positions of the solar

flares which produced energetic electrons are almost always located in the western hemisphere of the sun. This characteristic is very similar to that of solar cosmic ray events of both Bev and Mev energies. Accordingly, the propagation mechanism of these electrons is thought to be very similar to that of solar cosmic ray protons and heavier nuclei.

In this paper, we first consider the classification of energetic electron events which has been suggested by Lin and Anderson (1967) and then discuss the relation of the position of solar flares producing energetic electrons with the active regions associated with high type I radio noise activity. A brief discussion is given on the acceleration and ejection of energetic electrons.

Statistical Properties of the Solar Flares Associated with Electron Events

The observational data used here are described in the papers by Lin and Anderson (1967) and Lin (1970) and cover the period from 1964 to 1967 during the increasing phase of the solar activity cycle. In the papers cited above, Lin and Anderson classified the observed distinct electron events into two types which are defined as Simple and Complex types. Complex type electron events were associated only with the solar flares which occurred within the active regions where type I noise storm activity was high. As shown by Lin (1970), the mean position of the solar flares associated with Simple type electrons events is located more westward than the flares associated with Complex type electron events on the solar disk. This result is reproduced in Figure 1 (Lin, 1970).

The mean position of Simple event producing flares is located at about 60° west from the central meridian of the sun, whereas that of Complex event producing flares is located at about 10° west. This result can be seen from Figure 2, which shows the heliographic longitude distribution of solar flares which produced both Simple and Complex type events. In Figure 2a, both Simple and Complex type events are separately shown with respect to the heliographic longitude. By superposing both types of electron events, we obtain the heliographic longitude distribution of the total electron events as is shown in Figure 2b. In this case, it is clear that the most effective longitude of the solar flares which produce energetic electron events observed at the earth is located around 60° west from the central meridian of the sun. In this figure, the position of "over the limb" flares is added based on the correction of the occurrence time of these flares. This result suggests that the distinction between Simple and Complex type electron events is not real but only apparent.

In order to further examine the apparent distinction we statistically analyze the importance distribution of the solar flares associated with both Simple and Complex electron events. The importance of most solar flares associated with both these electron events is from 1F to 1B as shown in Figure 3. The mean flare importance for both electron events is 1N and, therefore, we find no difference between the characteristics of solar flares observed by Hα emission lines for the two types of electron events.

As described in the papers (Lin and Anderson, 1967; Lin, 1970), the same active region often produced both types of electron events several

times during their passage across the solar disk. These examples are shown in Figure 4 for eight cases. The numbers in the figure show the MacMath Numbers of the active regions. It follows from this figure that, as the active regions approach the western limb, the classification of electron events associated with the same active regions usually changes from Complex to Simple types. These facts suggest that, by some means such as the narrow emission cone we are unable to observe all of the type I noise storm active regions located for distant i.e. large helio-graphic longitudes from the central meridian of the solar disk. Therefore, Simple type electron events also seem to be generated from the solar flares which occur within the active regions where type I noise storm activity is high.

The distinction between Simple and Complex type electron events may, therefore, be due only to the narrow directivity of type I radio noise bursts. We know that type I radio noise bursts are usually emitted into a narrow cone above the sunspot active regions (e.g. Morimoto and Kai, 1961, Kundu, 1965; Fokker, 1965). Thus, generally speaking, we are often unable to observe type I radio noise storms or bursts associated with the active sunspot groups which are located far from the central meridian of the solar disk. Consequently, we do not need to consider the distinction between Simple and Complex type electron events and, therefore, we suggest that all of the solar flares which produce energetic electron events observed at the earth are generated within the active regions where type I radio noise activity is high. This

conclusion also seems to be valuable for an interpretation of the results shown in Figures 1 and 2.

The Relation to Solar Radio Type I Noise Activity

The directivity of sources of type I noise storm radiation can be demonstrated by looking for the percentage of sunspots that are observed relative to noise activity on different parts of the solar disk. This percentage decreases rapidly toward the limb as shown in Figure 5 (Fokker, 1965). It is clear from this figure that, near the central meridian, about 50% of sunspot groups are associated with type I noise storm activity, whereas about 10% or less of sunspot groups are associated with this noise burst activity near the limb.

If we assume that the solar flares which can produce energetic electron events only occur within the sunspot groups from which type I noise storms or bursts are actively emitted, all the solar flares associated with electron events must be located within these sunspot groups just mentioned. Accordingly, if such solar flares occur near the central meridian, all electron events must be of the "Complex" type. Furthermore, if such solar flares occur within the range from 30° to 40° west, about 60% of the electron events are expected to be "Complex" events, and the other 40% will be of the Simple type. By referring to the result shown in Figure 2, we can calculate the percentage of Complex events to all events with respect to heliographic longitude. The result of this calculation is shown in Figure 6. The cross marks indicate the expected percentage of Complex to all electron events in the different longitude zones of the solar disk, and the black line shows the smoothed curve for this expected percentage. The dashed line in this figure corresponds to the straight

line drawn in Figure 5. Both lines clearly show a very similar change with respect to the heliographic longitude. However, it should be noted that the percentage of Complex type electron events to all electron events is usually smaller than that of sunspots which are type I noise active for the major range of heliographic longitudes. This difference may be due to the excess appearance of Simple type electron events since the configuration of the interplanetary magnetic field is much more favorable for the propagation of energetic electrons streams ejected from solar flares which occur from the active regions located from about 40° to 80° west in heliographic longitude. The same interpretation will be applied to the Complex type events produced from the solar flares in the eastern hemisphere. Thus, this figure implies that Complex and Simple type electron events are both generated from solar flares which occur within the type I noise active sunspot groups. These type I noise regions seem to be active in producing the solar flares which can accelerate energetic electrons.

Acceleration of Energetic Electrons Associated with Type I Noise Active Regions

As is shown in Figure 6, the solar flares which produce energetic electrons occur within the sunspot groups which are active in the emission of type I noise storms or bursts. Therefore, the high probability of the occurrence of such solar flares may be related to the emission mechanism of type I radio noise storms. At present, it is thought that this noise

storm is generated by some non-thermal process which takes place above the active sunspot groups around a height of (0.2 - 0.3) $R_\odot$ ($R_\odot$ solar radius) (e.g., Morimoto and Kai, 1961; Kundu, 1965). Such a non-thermal process must take into account the role of energetic electrons which interact with ambient plasma or magnetic fields (e.g., Takakura, 1963; Fokker, 1965; Trakhtengarts, 1966). To interpret the origin of type I radio noise storms, we cannot neglect the existence of energetic non-thermal electron beams which inevitably interact with the ambient plasma and magnetic fields.

Above the sunspot groups which are associated with the emission of type I noise storms, the clusters of the enormous number of energetic electrons must, therefore, be trapped by the sunspot magnetic lines of force. The speed of these electrons is estimated to be at least two times the thermal velocity of the ambient electrons (Takakura, 1963). This result suggests at such energetic electrons always exist and are continuously generated in the sunspot groups which produce type I noise storms.

These sunspot groups are also very active in producing such solar flares and energetic electron beams responsible for the excitation of type I noise storms. We can, therefore, conclude that these sunspot groups are continuously producing the energetic electrons responsible for type I radio noise emissions and sometimes produce the energetic electron emissions associated with solar flares which are observed as distinct electron events by satellites at the earth's orbit. The model of such sunspot groups is schematically shown in Figure 7. In the solar corona high above the active regions, the neutral plasma layers seem in general to be formed as shown in the figure. If the energetic electron streams pass through these layers after ejection from flare sites, they may always trigger some instability there. In general, this neutral layer

instability appears to be responsible for the emission of type III radio bursts, which are excited by the energetic electon beams associated with this instability.

In order to study the acceleration of these energetic electrons associated with solar flares, various energy loss processes in the electron accelerating regions must be examined (Sakurai, 1967, 1970). In the case of these energetic electrons, the initial injection process is most important since the secondary acceleration process is not very effective in changing the injection energy of the electrons. The latter process may become important if we consider the acceleration mechanism for relativistic electrons (e.g., Sakurai, 1965, 1970). It, therefore, seems that small solar flares of importance 1B or less (see Figure 3) are only able to accelerate electrons rapidly to an energy just above the injection value. According to the estimation made by Sakurai, (1967) the energy range of the electrons thus accelerated is usually from 10 to 100 Kev if we assume that the plasma number density and the intensity of magnetic field are $\sim 10^8$ cm^{-3} and $\sim 10^3$ gauss, respectively in the accelerating regions. Taking into account that the injection energy of electrons must be about at least 10 Kev in such accelerating region, the electrons that are accelerated in solar flares would be the ambient suprathermal electrons and their tail component. These electrons would be responsible for the emission of type I radio noise storms. Perhaps at the initial stage of their development, solar flares which occur at the bottom

regions of active sunspot groups would suddently accelerate energetic electrons to the energy $\gtrsim$ 40 Kev as observed at the earth's neighborhood (Figure 7). Some fraction of these energetic electrons are ejected from the accelerating regions into outer space and are observed as distinct electron events (Figure 7b). Some of these electrons are ejected into the higher density and strong magnetic field regions as shown in Figure 7b where they generate X-ray and microwave impulsive bursts. In association with such solar flares, type I noise storm activity would be enhanced due to the supply of accelerated energetic electrons.

Concluding Remarks

The relation of the type I noise active sunspot groups to the occurrence of the solar flares which produce distinct electron events has been considered in this paper. It has been shown that all of these solar flares occurred within the sunspot groups which were highly active in emitting type I noise storms or bursts.

By continuously observing the development and passage of the sunspot groups which are active in the emission of type I noise storms or bursts, it should be possible to predict the occurrence of solar flares which can generate energetic electrons that will arrive at the earth's orbit. In this case, we must keep in mind the tendency of the type I noise storms or bursts to be emitted into the narrow cone extending upward from the active sunspot groups. Then it becomes difficult to detect the type I noise activity which comes from active regions located at large heliographic longitudes from central meridian. Taking this tendency into consideration,

we have shown that the distinction between Simple and Complex type electron events (Lin and Anderson, 1967; Lin, 1970) is not essential, but is due to the narrow directivity of type I noise storms or bursts.

Only a qualitative picture was given in the last section of the relation of energetic electrons associated with solar flares to ambient suprathermal electrons responsible for the emission of type I noise storms. This problem must be extensively pursued as a next step in the study of the acceleration mechanism of energetic electrons associated with solar flares which occur within the type I noise storm active regions.

Acknowledgements

I wish to thank Dr. R.G. Stone and Dr. J. Fainberg for their helpful discussion and criticism on this work. I also thank Dr. R.G. Stone for his critical reading of the manuscript.

References

Anderson, K.A. and Lin, R.P., Observations on the propagation of solar flare electrons in interplanetary space, Phys. Rev. Letters, 16, 1121-1124 (1967)

Fokker, A.D., Noise storms, in Solar System Radio Astronomy, pp. 171-199, edited by Aarons, J., Plenum Press, New York (1965).

Kundu, M.R., Solar Radio Astronomy, John Wiley, New York (1965).

Lin, R.P., The emission and propagation of solar flare electrons, 1. The relationship of ~ 40 Kev electron to energetic proton and relativistic electron emission by the sun, Solar Phys., 12, 209 - (1970)

Lin, R.P. and Anderson, K.A., Electrons >40 Kev and protons >500 Kev of solar origin, Solar Phys., 1, 446-464 (1967).

Morimoto, M. and Kai, K., The height of the solar radio bursts at 200 Mc/s, Pub. Astron. Soc. Japan, 13, 294-302 (1961)

Sakurai, K., The adiabatic motion of charged particles in varying magnetic fields, Rep. Ionos. Space Res. Japan, 19, 421-432 (1965)

Sakurai, K., Energetic electrons associated with solar flares, Pub. Astron. Soc. Japan, 19, 316-322 (1967)

Sakurai, K., On the acceleration of relativistic electrons in solar flares, NASA Preprint series in preparation (1970)

Takakura, T., Origin of solar radio type I bursts, Pub. Astron. Soc. Japan, 15, 462-481 (1963)

Trakhtengerts, V.Ya., A theory for type I solar radio bursts, Soviet Astronomy - AJ, 10, 281-287 (1966)

Van Allen, J.A. and Krimigis, S.M., Impulsive emission of ~40 - Kev electrons from the sun, J. Geophys. Res., 70 : 5737 - 5751 (1965)

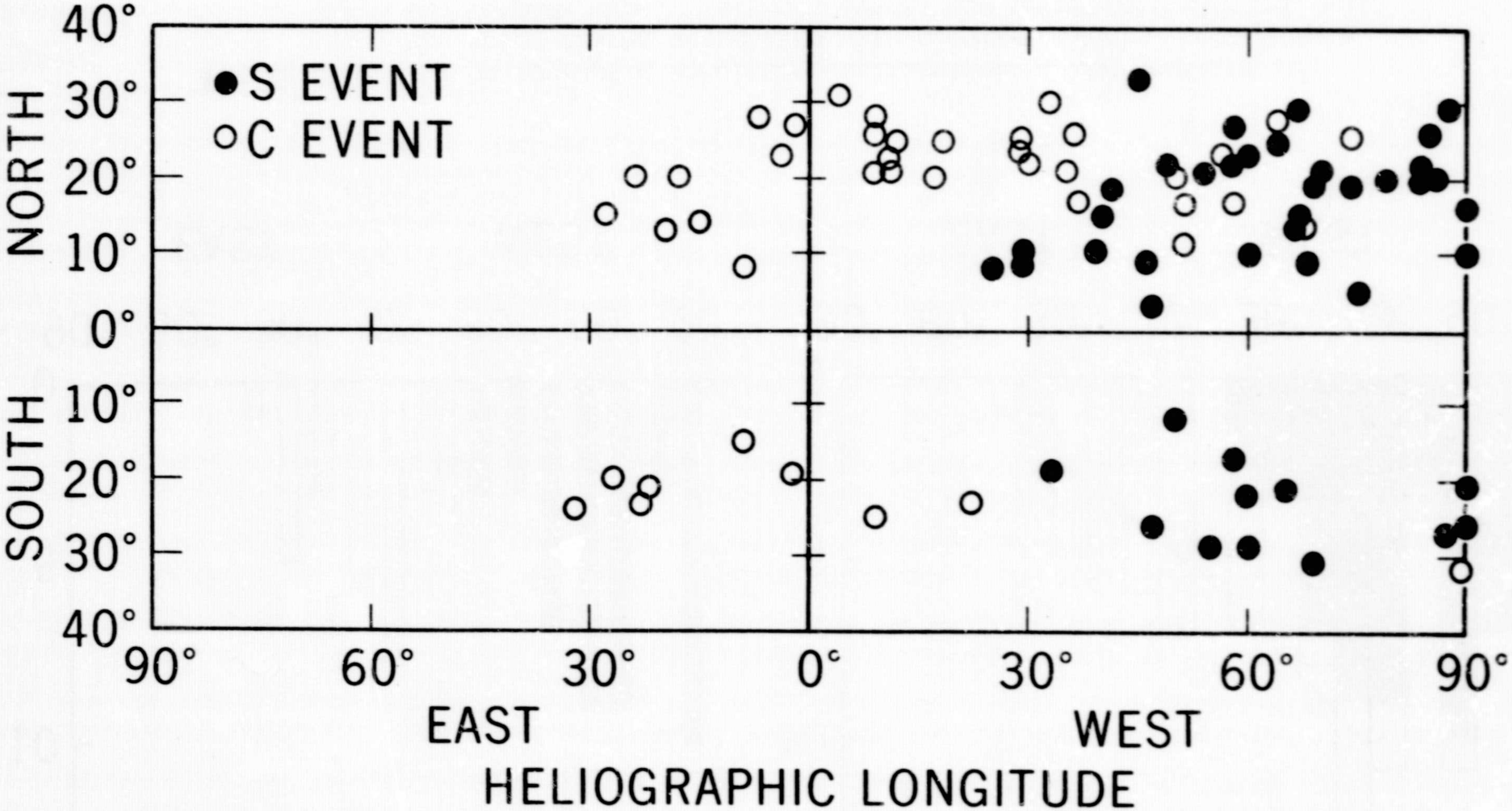

Figure 1 - The distribution of the position of the solar flares which produced both Complex and Simple type electron events on the solar disk. The filled and open circles indicate the Simple and Complex type electron events, respectively (After Lin, 1970).

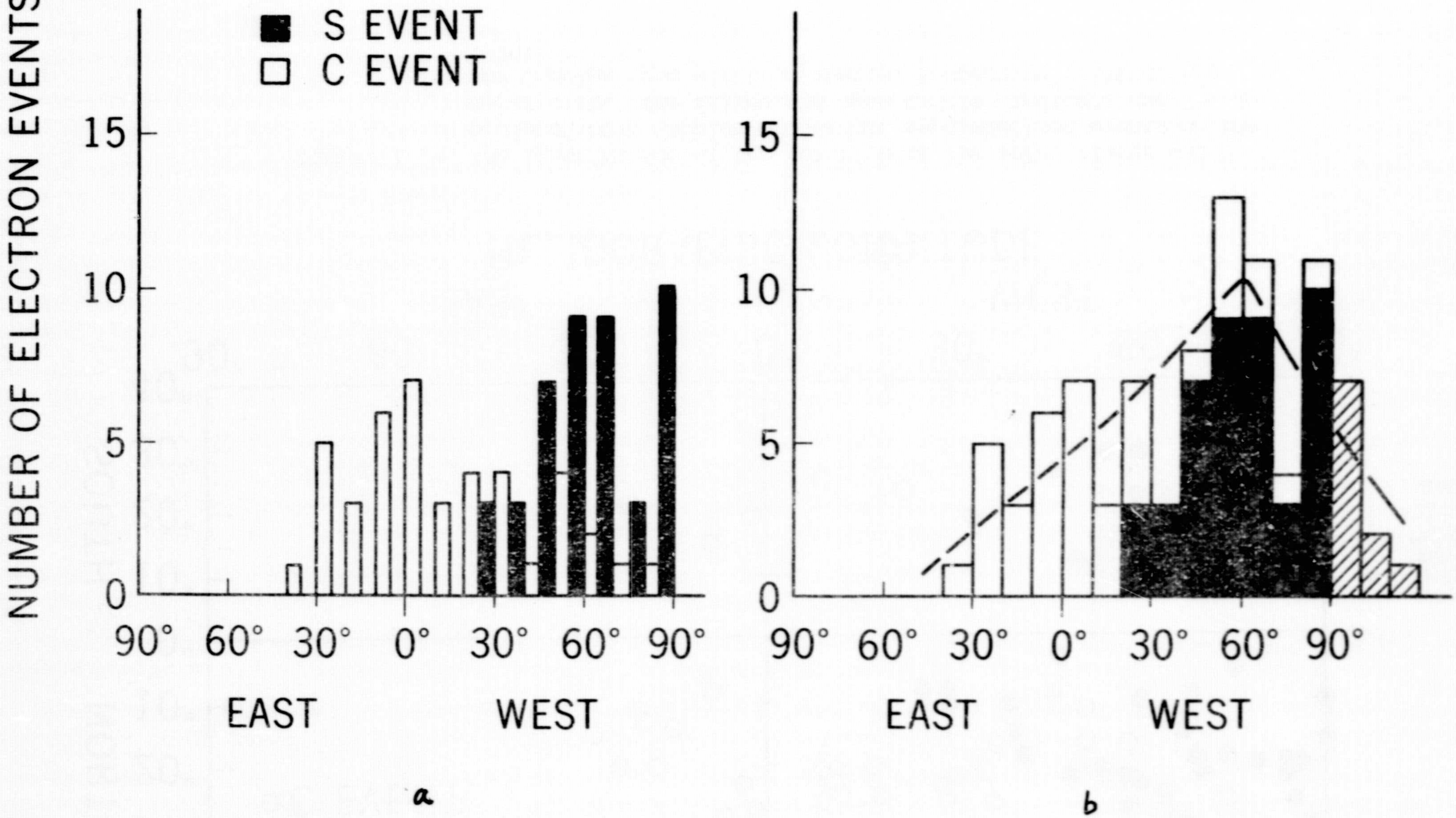

Figure 2 - The heliographic longitude distribution of the position of the solar flares associated with electron events, both Simple and Complex type. (a) Both events are separately plotted, and (b) both events are superposed.

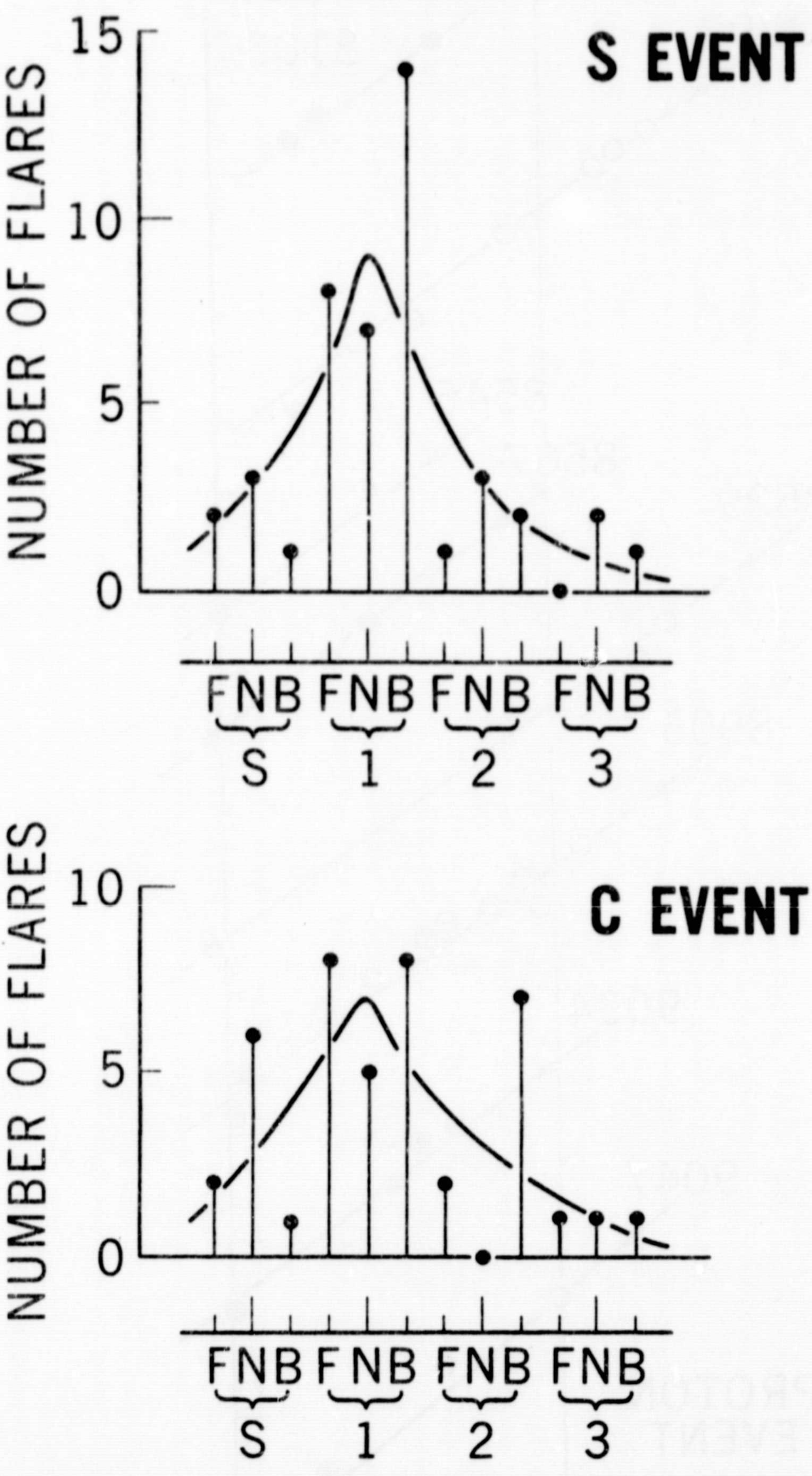

Figure 3 - The distribution of the importance of solar flares which are associated with Simple and Complex electron events.

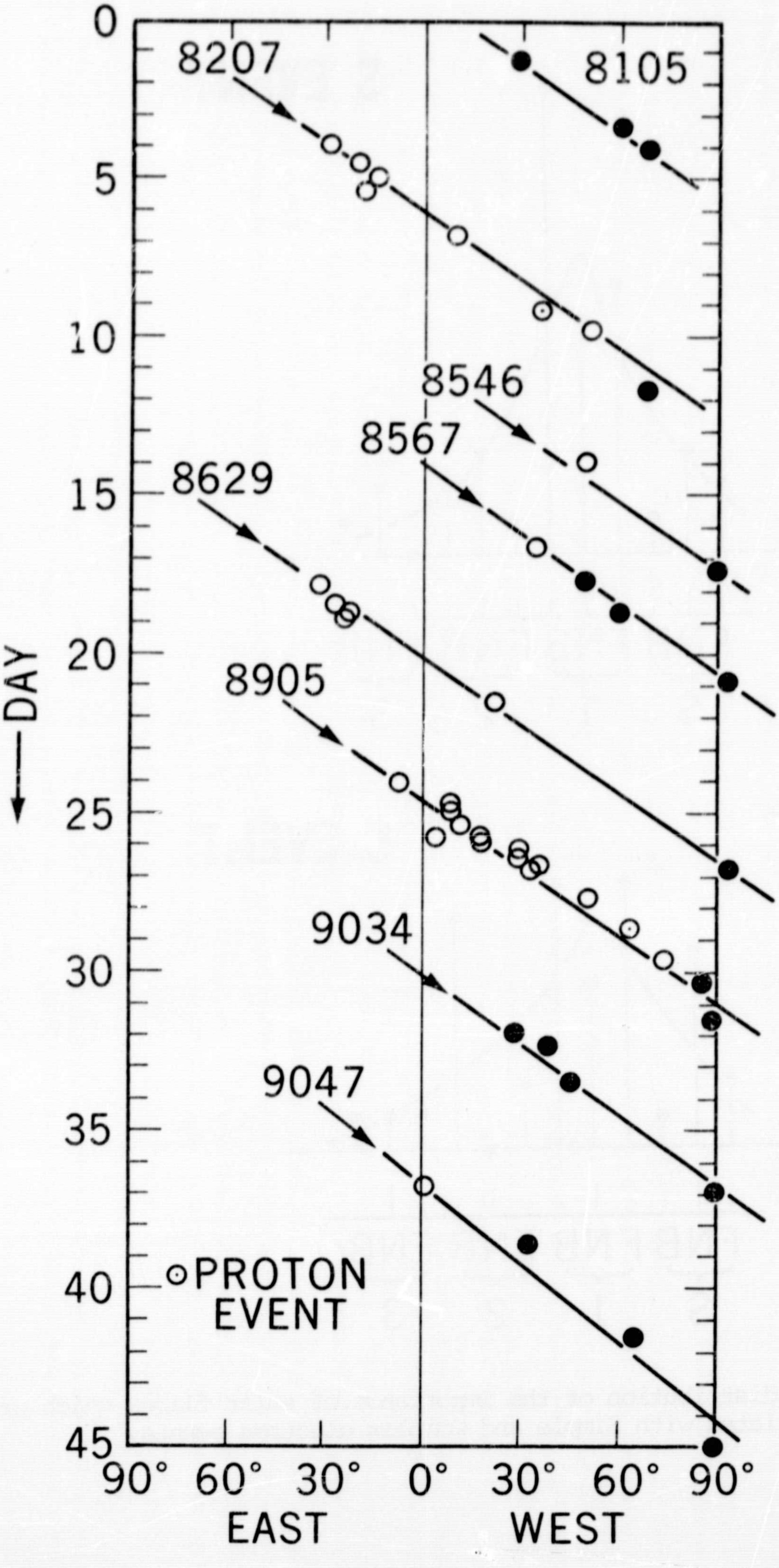

Figure 4 - The relation of the type of electron events with the position of parent solar flares in association with the westward movement of type I noise active sunspot groups. The numbers express the MacMath numbers of each active region.

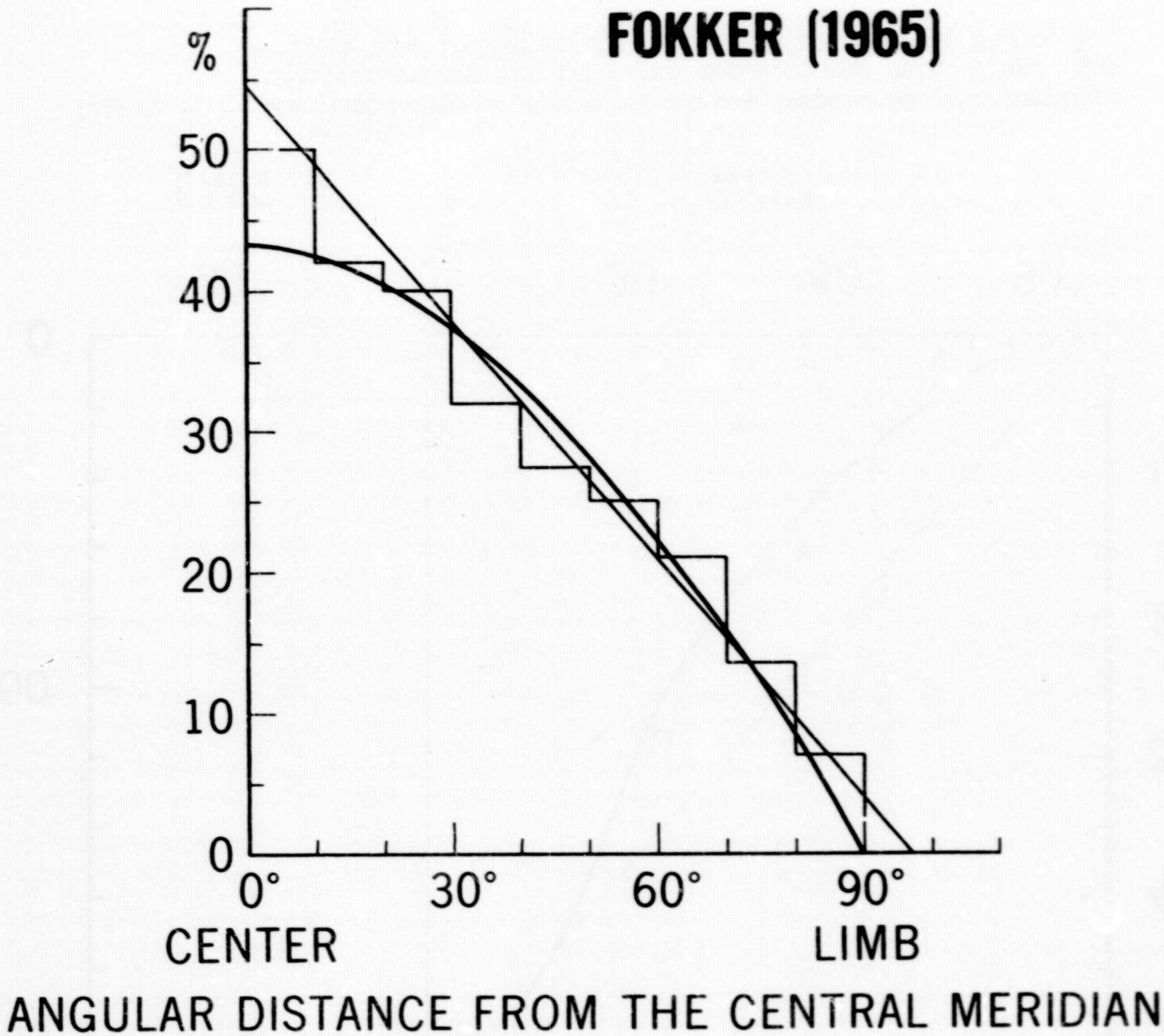

Figure 5 - The percentage of sunspots that are type I noise active for different zones of the solar disk (After Fokker, 1965).

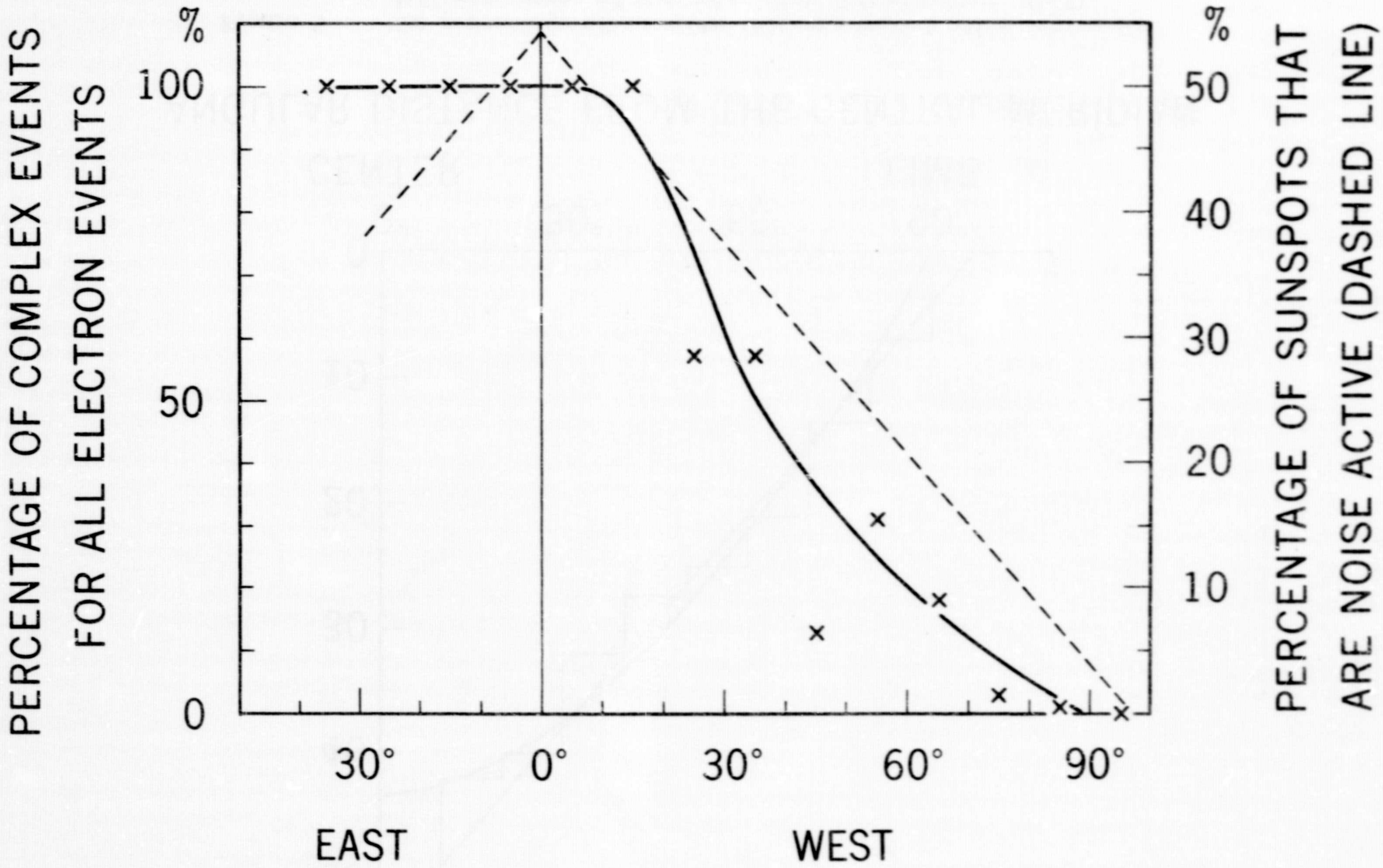

Figure 6 - The percentage of the solar flares associated with Complex electron events for different zones of the solar disk. The dashed line indicates the percentage as shown in Figure 5.

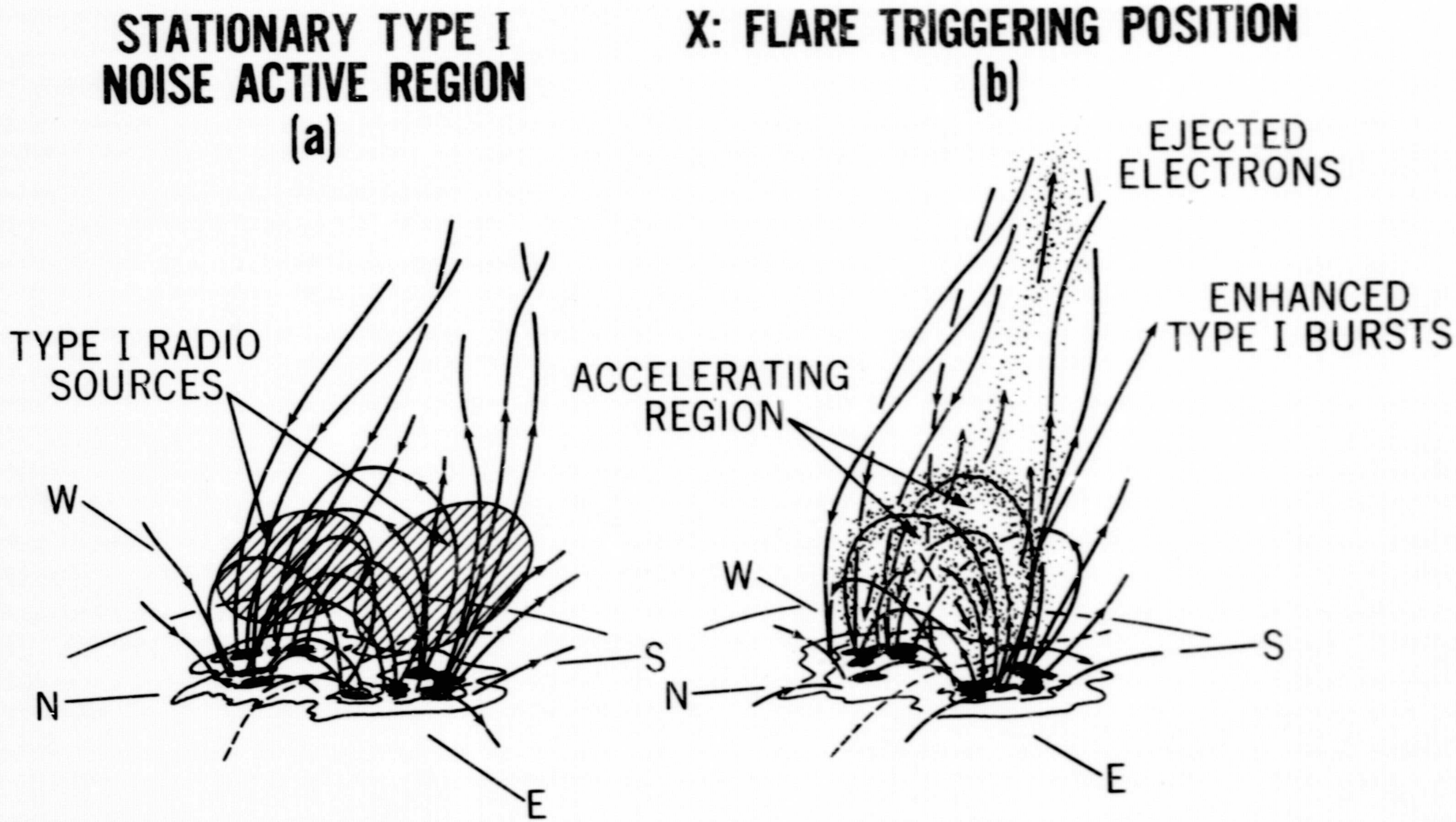

Figure 7 - The model of type I noise active regions (a) stationary active regions. Type I radio source are located above both preceding and following sunspot groups. (b) In association with the onset of a solar flare, the sunspot magnetic configuration is violently disturbed and accelerated electrons are then ejected to the lower chromosphere or photosphere and also to outer space.